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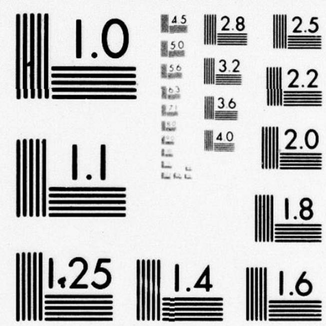

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

A CONCEPTUAL DESIGN OF A LIGHTER-THAN-AIR
TEST AND RESEARCH VEHICLE

by

Richard Patrick Glover

June 1979

Thesis Advisor: D. M. Layton

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An analysis of conventional lighter-than-air vehicles was conducted to determine if a modular design approach was feasible. Once this was accomplished, a conceptual design using the modular approach is presented for a vehicle to serve as a platform for conducting lighter-than-air flight tests and research. In addition, a general discussion is included on the program management organization, flight tests, and instrumentation of such a vehicle.

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A Conceptual Design of a Lighter-than-Air
Test and Research Vehicle

by

Richard Patrick Glover
Lieutenant, United States Coast Guard
B.S., University of the State of New York, 1978

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

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ABSTRACT

An analysis of conventional lighter-than-air vehicles was conducted to determine if a modular design approach was feasible. Once this was accomplished, a conceptual design using the modular approach is presented for a vehicle to serve as a platform for conducting lighter-than-air flight tests and research. In addition, a general discussion is included on the program management organization, flight tests, and instrumentation of such a vehicle.

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LIST OF SYMBOLS AND ABBREVIATIONS

A	Total Horizontal or Vertical Tail Area
AEW	Airborne Early Warning
ASW	Anti-Submarine Warfare
C	Constant
C_v	Cylindric Coefficient
D	Maximum Vehicle Diameter
db	Decibel
dia	Diameter
ELT	Enforcement of Laws and Treaties
EPA	Environmental Protection Agency
F	Force
F	Fineness Ratio
ft	Feet
FAA	Federal Aviation Administration
HLA	Heavy Lift Airship
ICBM	Intercontinental Ballistic Missile
L	Vehicle Length
LTA	Lighter-than-Air
MBITS	Million Binary Digits
MEGABITS	" " "
MEP	Marine Environmental Protection
MIC	Module Interfacing Component
NASA	National Aeronautics and Space Administration
q	Aerodynamic Pressure

SAR	Search and Rescue
V	Vehicle Volume
v	Velocity
V/STOL	Vertical/Short Takeoff and Landing
VTS	Vessel Traffic System
ρ	Density

ACKNOWLEDGEMENT

In memory of my father, mother and brothers.

I. INTRODUCTION

A. BACKGROUND

The emergence of Lighter-than-Air (LTA) technology approaches to modern transportation problems has increased steadily in the last few years. The advent of breakthroughs in high-strength, low-weight materials, the increased fuel cost, and the large lift capabilities of airships have helped to renovate an aeronautical idea once condemned in its infancy. The capability to carry large, indivisible loads economically seems unsurpassed even by the largest of helicopters. A brief review of this interest is given below.

Interest in LTA in the United States, both commercially and in government/military service, is becoming more intense. The use of the heavy-lift airship (HLA) concept, as shown in Figures 1 and 2 from Ref. 1, is proposed for use in the lumber industry and cargo handling. The use of the HLA for unloading vessels in logistical support of amphibious forces is envisioned in the military role.

The necessity for mid-ocean surveillance referred to by Ref. 2 has become a candidate mission for LTA in the U.S. Navy. Antisubmarine Warfare (ASW) [Ref. 3] and Airborne Early Warning (AEW) roles are once again being discussed as LTA contributions. Both ASW and AEW missions have been conducted in the past successfully by LTA vehicles in Navy service.

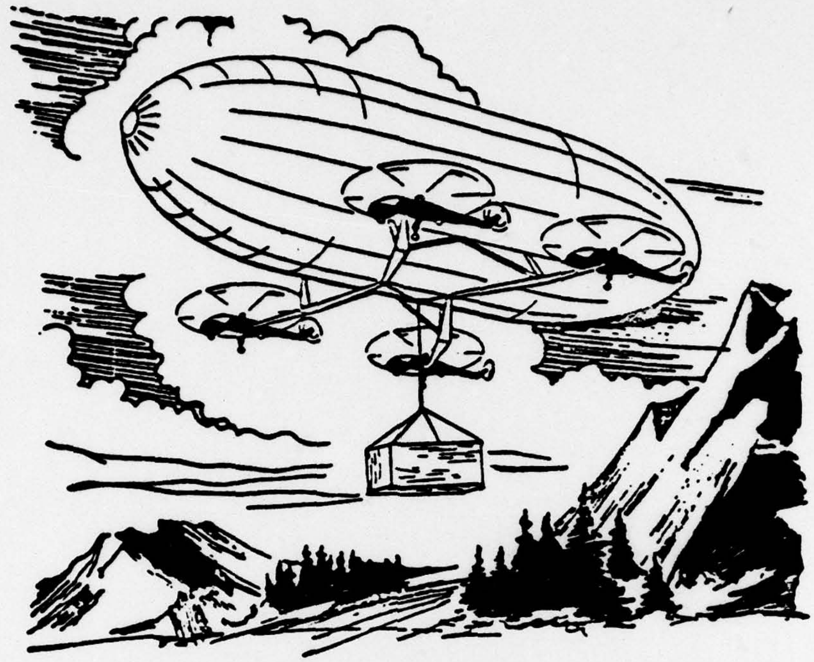

Fig. 1. Heavy Lift Airship Concept

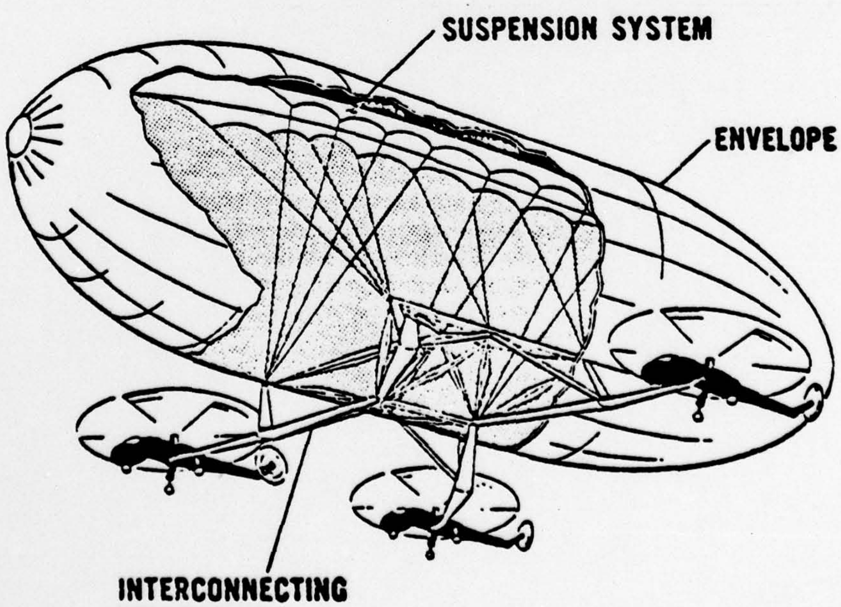

Fig. 2. Major Structural Components of HLA

The U.S. Coast Guard has indicated interest in LTA vehicles due to the ability of the vehicle to patrol large over-water areas economically in much the same manner as a surface vessel. The missions of Enforcement of Laws and Treaties (ELT) and Search and Rescue (SAR) could be well served by such a vehicle. The ability to carry and deploy large loads makes the vehicle attractive for the Marine Environmental Protection (MEP) mission where oil booms and other pollution response devices must be delivered on scene quickly. These uses are delineated further in Refs. 4 and 5.

The ability of the vehicle to hover using modern technology such as advance rotor designs, makes such a vehicle well suited in missions requiring hoisting or boat launch operations, thus allowing boarding and rescue operations to take place.

The tethered balloon could possibly have roles in communications, surveillance, and traffic management in the Vessel Traffic System (VTS) and other roles. The area of tethered balloons has not, however, been studied to a large extent by the Coast Guard.

The possibility of use of LTA for U.S. Air Force missions has also been examined [Refs. 6 and 7]. These possible uses could include logistical support as well as ballistic missile early warning platforms. It is even conceivable that an advance design LTA vehicle could be used in cruise missile carrier or Intercontinental Ballistic Missile (ICBM) interception roles.

Foreign concerns in LTA have also undergone a growth. The United Kingdon interest also lay in the use of the vehicle for ELT and missions similar to that of the U.S. Coast Guard. The surveillance and management of maritime traffic in the Dover Straits by such a vehicle could aid in the prevention of a major collision in this heavily transited area.

The United Kingdom Ministry of Agriculture and Fisheries has indicated a need for a vehicle capable of boat launch and area surveillance. The surveillance role is presently being carried out by the Nimrod aircraft at quite a substantial cost.

Although French coastal surveillance and meteorological research is a candidate use, the French interest appears to be mainly one of commercial orientation. The ability to deliver large cargo payloads to European and undeveloped African areas appears quite promixing. The major advantage of LTA in this regard is in the elimination of intermodal transfer involved in truck, rail, and aircraft used at present.

Japanese interest also appears primarily commercial in nature. The use of a Japanese-built HLA for lumber operations in the People's Republic of China as well as other Chinese industrial uses could revolutionize these operations.

In the Soviet Union the interest in the LTA approach has been also displayed [Refs. 8, 9, and 10]. However, non-technical policies have temporarily delayed this effort [Ref. 11].

A Canadian interest in the HLA concept for use in timber operations has also been indicated.

This is but a small sample of the interest shown in the use of LTA in the world today.

Feasibility studies on LTA abound, mostly developed on experiences gained many years past. The airship has been shown to be both feasible and infeasible in these studies. However, no verification exists on any of these works since operational vehicles were not constructed or evaluated.

Advance designs for modern LTA vehicles also abound, from unique envelope shapes to hybrid lifting body vehicles [Refs. 12, 13, and 14]. Although these designs may have merit, so far they have been but academic exercises, and no large-scale vehicles have been developed.

B. APPROACH TO THE PROBLEM

The original plan for this work was to complete a design for a hybrid vehicle utilizing high lift, subsonic airfoil sections with helium lift augmentation. The airfoil shapes were chosen for their high thickness-to-chord ratios, thereby allowing maximum volume for the lifting gas. Reference 15 discusses airfoil shapes meeting this requirement. The possible integration of the concept proposed by Rogallo [Ref. 16] for flexible airfoils was also considered. Foil shapes were chosen for maximum lift coefficients at points of maximum weight concentration. Therefore, foil shape varied across the span presenting costly construction. The major design

constraint considered in the vehicle was its vertical dimension. This was done so that existing hangar facilities could be used. However, due to this constraint, such a vehicle would not be neutrally buoyant, and hover would require higher power than was necessary for normal flight.

Although work on this project proceeded into the conceptual design phase, a change in goal was determined to be necessary for a real contribution to the advancement of LTA technology. As previously mentioned, many hybrid designs already exist for the user to choose from, but no full-scale vehicles have evolved.

Therefore, it was determined that prior to the advent of these or other modern LTA concepts, a test vehicle must be constructed and data collected to fill in voids that have existed for so many long years. This was proposed by Arnstein and Klemperer in 1934 [Ref. 17]. However, such a vehicle or program never materialized. As pointed out by Vorachek [Ref. 18], most of the data on LTA vehicles has come from operational vehicles constructed and configured for their various missions, but no dedicated test vehicle was constructed.

This thesis will examine and propose a conceptual design for an LTA test vehicle as well as a general test program approach. It is by no means intended to be the ultimate answer but does present a stepping-off point which is necessary for future work.

II. PROGRAM MANAGEMENT ORGANIZATION

Prior to the actual hardware considerations of an LTA test program, the organization of the program management must be examined.

Many offices in both military and civil agencies are attempting to develop viable programs as indicated previously. Even though the exchange of ideas and information between these organizations is generally free from obstruction, several problem areas challenge a successful endeavor using this approach. Intra-agency rivalries and subjective evaluations sometimes block progress. The idea that an LTA vehicle would present competition to current resources will, in some cases, prevent a completely cooperative effort. However, it is felt that LTA vehicles are unique in nature and should not be used in direct comparison.

The inefficiency and cost penalties of having many offices conduct individual programs in such related goals is also self-evident.

Therefore, an LTA program organization is proposed as shown in Figure 3. This would consist of an interagency program office composed of members of the various agencies of interests. This office would function to coordinate efforts, gather data and mission requirements, and integrate these into one, multi-agency effort.

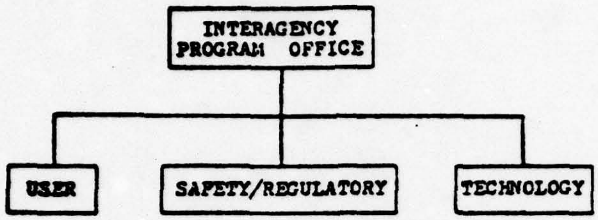

Fig. 3. Program Management Organization Chart

Below this office would be grouped the agencies and organizations of interest within three groups: user, technology, and regulatory/safety.

The user group would consist of agencies and organizations with a user interest in LTA. Examples of these are Department of Defense, U.S. Coast Guard, and Department of Commerce. The input from this group would mainly be that of user requirements and operational interface of the vehicle.

The technology group would consist of agencies and organizations such as National Aeronautics and Space Administration (NASA), industry, universities and government laboratories, who would continually examine and report possible new technology implementation and impacts on LTA. This group would be tasked with the technology data input requirements.

The regulatory/safety group would consist of members of agencies such as Environmental Protection Agency (EPA) and

Federal Aviation Administration (FAA) and others concerned with the safety of operation and regulatory constraints imposed on an LTA vehicle. The integration of an LTA vehicle into a safe operating environment for all would be the responsibility of this group.

Although such an organization would appear bureaucratic, it is intended to function as a goal oriented organization, and as such, it would be the most expedient and efficient means of any serious effort.

The inputs from the groups would provide information for the development of specifications for a specific test vehicle and program. However, for this paper, a general conceptual approach to the vehicle and program is proposed.

III. CONCEPTUAL DESIGN

A. GENERAL APPROACH

Due to the nature of the vehicle proposed, it is felt that to ensure maximum utilization, a low-risk approach is desired. A conventional, non-rigid vehicle constructed of modern materials and utilizing state-of-the-art design where possible would provide this level of risk. Although multi-lobed envelope shapes such as the tri-lobed vehicle shown in Figure 4 could be considered in this category, the more common shape used by U.S. Navy non-rigids is proposed. It is felt that this shape would allow better verification of wind-tunnel and calculated data due to the simplicity of shape and past testing. Vehicles of this shape are now operational both in this country and abroad.

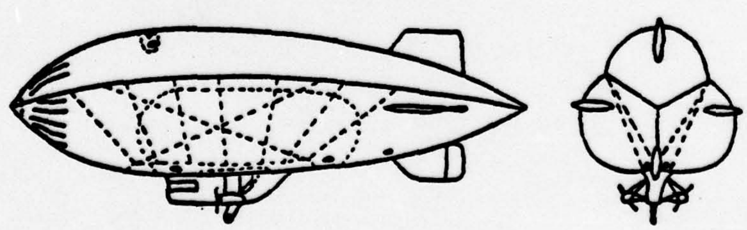

Fig. 4. A Typical Tri-Lobed Airship [Ref. 19]

Figure 5 shows the general arrangement of the proposed vehicle. Although the vehicle does not appear to be of a revolutionary nature, the manner of its construction will utilize a modular concept allowing reconfiguration for data collection.

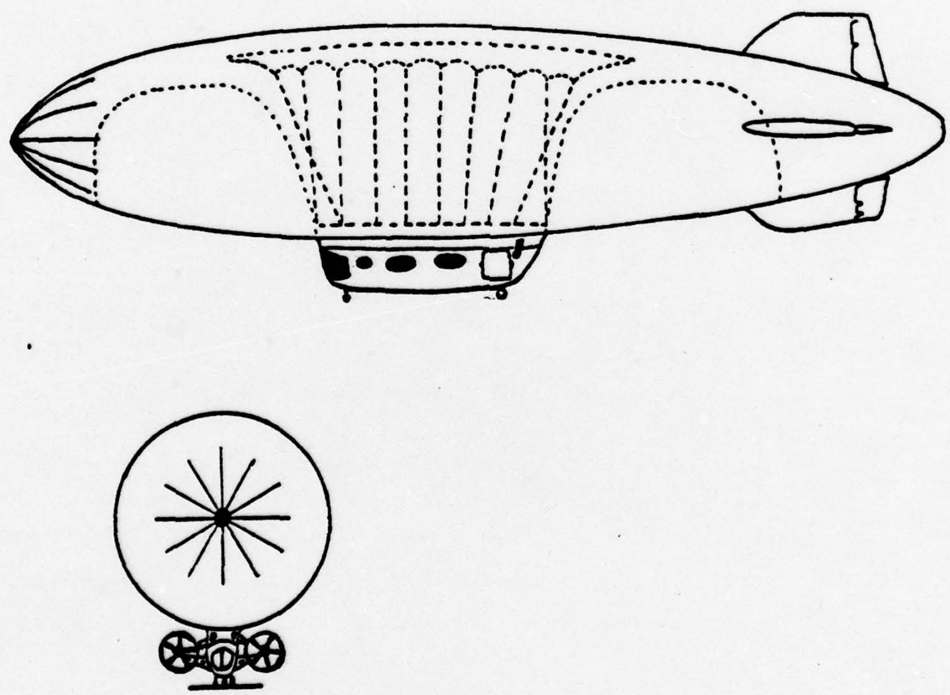

Fig. 5. General Arrangement of Test Vehicle

A partial modular concept was proposed in Ref. 1 to be utilized in an Airport Feeder Vehicle using LTA for a semi-buoyant passenger and cargo transport. This vehicle, shown in Figure 6 from Ref. 1, proposed a modularized cargo/passenger design for the payload cabin as shown in Figure 7. It would carry either passenger or cargo modules, or a combination of both. Although this vehicle would present a possible approach to a test and research vehicle, further examination of general airship configurations indicates a more universal modular approach as originally conceived by Professor Layton and the author, wherein the entire car/payload system is a detachable module.

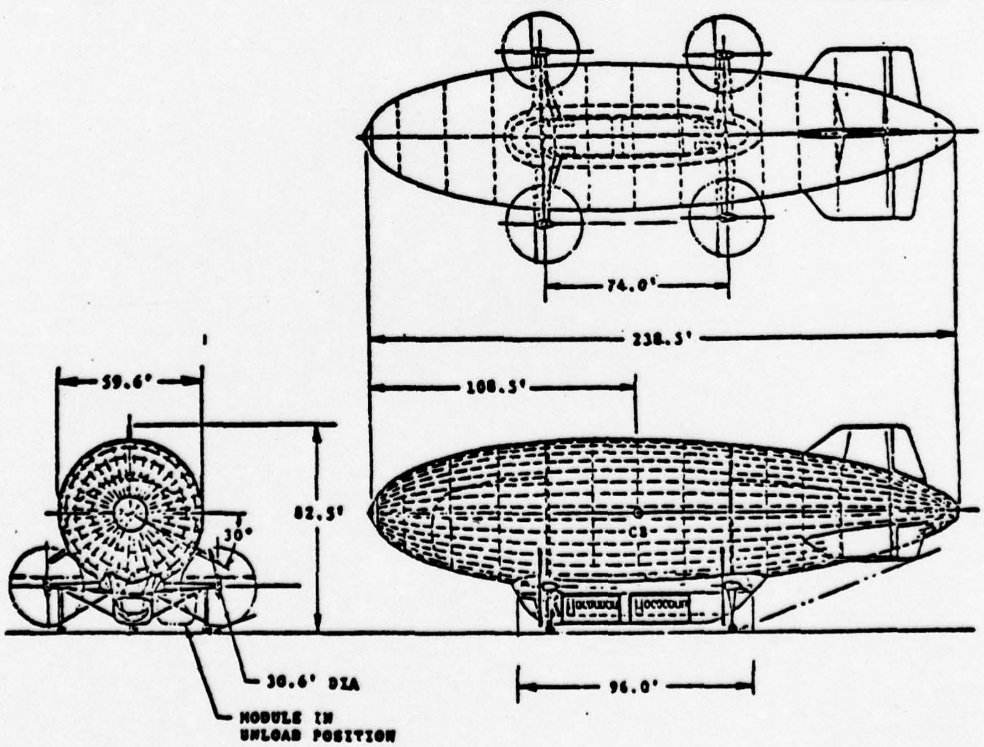

Fig. 6. Airport Feeder Vehicle

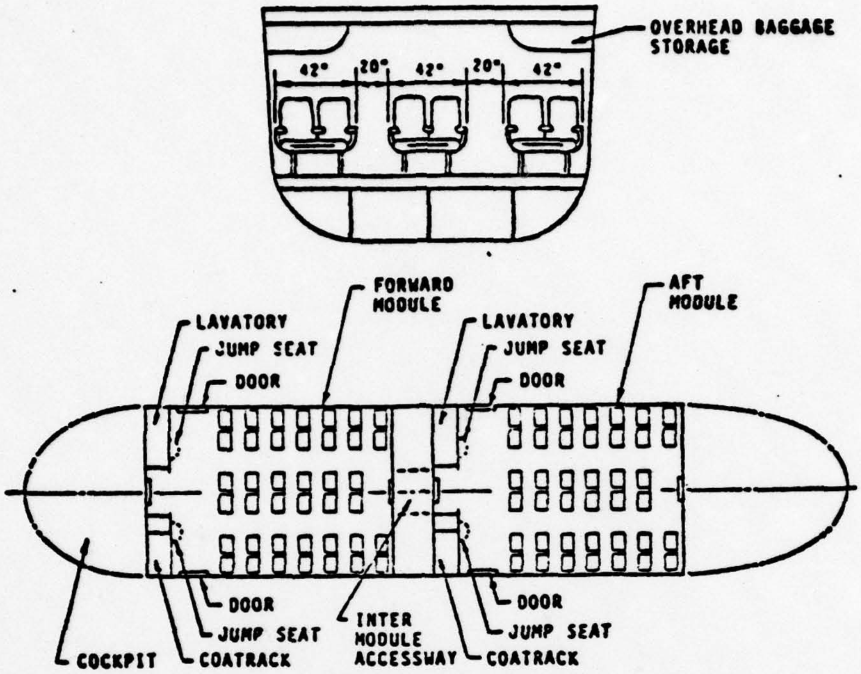

Fig. 7. Two-Segmented Payload Module Cabin Layout for Airport Feeder Vehicle [Ref. 1]

B. GENERALIZED VEHICLE

The generalized airship can be categorized into three distinct groups: envelope, car/payload, and empennage. These groups contain major components that once integrated form the operational vehicle. Each group has its own purpose in the overall operation of the vehicle.

The envelope group provides the lift, both dynamically and aerostatically, for the vehicle. It also provides structural support for the car/payload and empennage groups. This support is provided by both internal and external catenary curtains connected to the loads by suspension cables.

The nose cone and battens provide bow stiffening for the vehicle. This is necessary due to airloads in flight and the mooring loads encountered when the vehicle is moored out. The airloads due to flight depend on the nose pressure encountered during flight conditions. This is discussed by Munk in Ref. 20, and can be determined either analytically or by use of wind-tunnel tests. For the mooring loads, Burgess [Ref. 21] suggested an approximation for determining transverse forces on an airship moored out. This is given by:

$$F = C\,q\,V^{2/3} \tag{1}$$

where: F = transverse force,

C = a coefficient = 0.12,

V = the air volume of the airship,

q = the aerodynamic pressure = $\rho v^2/2$,

ρ = air density,

v = wind velocity.

It may become necessary to handle the vehicle during crosswinds for ground operations, thereby not allowing the vehicle to weathercock into the wind. If this becomes necessary, then hardpoints on the envelope may be required. Burgess [Ref. 21] gives a formula for the calculation of forces in a crosswind as:

$$F = 0.2\ LD\rho v^2 \qquad (2)$$

where: F = cross wind force

L = length of vehicle

D = diameter of vehicle.

This force is divided by the number of hardpoints on the vehicle.

Internal air chambers, called Ballonets, are provided to maintain the shape of the vehicle regardless of altitude. At sea level the vehicle contains a large percentage of lifting gas with the remainder of the volume occupied by air in the Ballonets. As the vehicle climbs, the lifting gas expands, and air is expelled from the Ballonets, thereby maintaining envelope shape without loss of lifting gas. The rate at which the air can be expelled from the Ballonets determines the maximum rate of ascent of the vehicle, and the rate at which air can be returned to the Ballonets, the rate of descent.

The air system, such as shown in Figure 8, determines the rate of air flow to and from the Ballonets. The air comes in through the air intake, through damper valves to the forward and aft Ballonets. The auxiliary blower is used when the engines are secured or the airspeed is not great enough to supply the air needed. Air discharge follows the path shown in the figure. An air duct to the gas space is provided to maintain helium pressure in case of a rip in

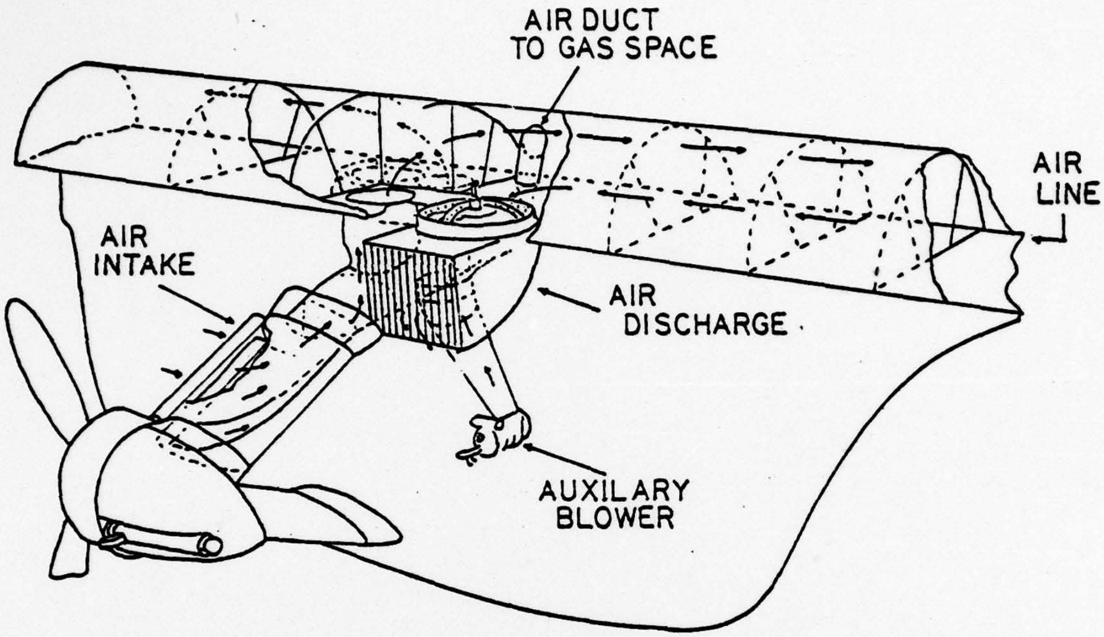

Fig. 8. Typical Airship Air System Configuration

the envelope. This duct is normally tied off and opened only in an emergency situation.

Besides maintaining envelope shape, the Ballonets also provide a means of trimming the airship in flights. By having the forward Ballonet fuller than the aft Ballonet, a nose down trim can be established due to the aft shift of the center of buoyancy. It can be seen that "pumping air" forward or aft in an airship performs the same function as pumping water ballast forward or aft in a submarine to provide trim. Therefore, the differential of the amount of air between the forward and aft Ballonets can be related to a weight differential.

The car/payload group provides for the propulsion, fuel storage, payload, and command and control of the vehicle. Water ballast storage is also provided in this group as well as landing gear support.

The car/payload group can be generally divided into three distinct areas: flight deck, payload, and engineering. These can best be demonstrated by the Aerospace Development's AD-500 Airship [Ref. 22]. The flight deck serves the same purposes as it does for conventional aircraft. In the AD-500 the payload area contains passenger seating; however, this area is usually mission oriented and, therefore, varies from vehicle to vehicle. The engineering area provides space for the propulsion system and associated equipment. In the AD-500, components of the air system are also within this area.

The empennage group provides for control of the vehicle during flight using tail control surfaces. These surfaces, connected to the control car through control cables, are secured to the envelope by suspension cables to the external catenaries. The bases of the control surfaces are usually mounted on reinforced areas of the envelope called "shoes."

The surfaces can be constructed either by means of fabric covered structures or inflatable surfaces. However, advancements in composite materials also make this approach attractive.

The configuration of the tail control surfaces around the envelope is usually one of three configurations shown

in Figure 9. Reference 23 discusses model tests of vehicles differently configured and the results of these tests. These results indicated that the X-tail provided the smallest minimum turning radius while exhibiting the best yaw stability. The inverted Y-tail and the X-tail provide minimum ground clearance during take-off. However, further examina- of tail configuration may be necessary on full-sized vehicles.

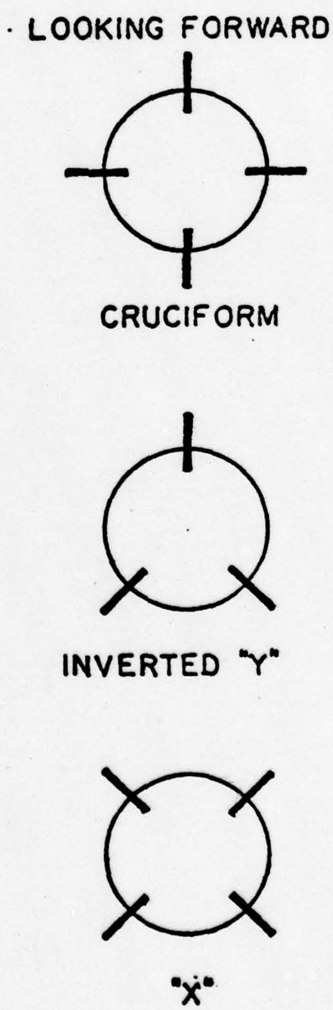

Fig. 9. Possible Airship Empennage Configurations.

Burgess [Ref. 24] presented an empirical expression for determining the vertical or horizontal tail surface areas. This expression, used in preliminary design, is given by:

$$A = 0.13V^{2/3} \tag{3}$$

where: A = total area of vertical or horizontal tail surfaces

V = volume of airship

This expression gives the total horizontal or vertical areas; therefore, each individual surface would require one-half this value. A plot of equation (3) is given as Figure 10. Appendix A examines various operational vehicles, and where possible compares the area given by equation (3) to the actual area of these vehicles. It is interesting to note that the actual areas appear to be approximately 16 to 19 percent greater than that given from this equation.

This completes a brief discussion of the three main vehicle groups. To determine the ability to modularize the vehicle, examination of the interface between these groups is necessary.

C. EMPENNAGE MODULE

Figure 11 shows the major interface requirements between the three main groups. The interface requirements of the empennage group are accomplished without much complexity. These requirements have been approached almost identically

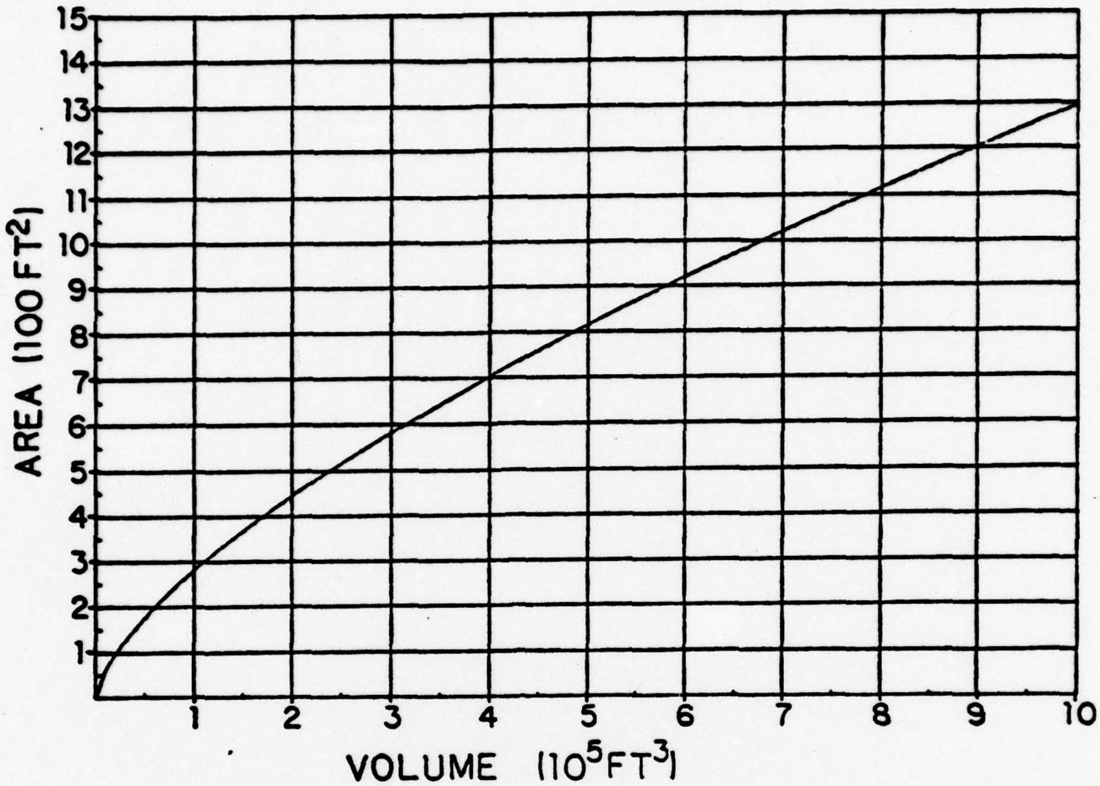

Fig. 10. Plot of Total Horizontal or Vertical Tail Area vs. Envelope Volume

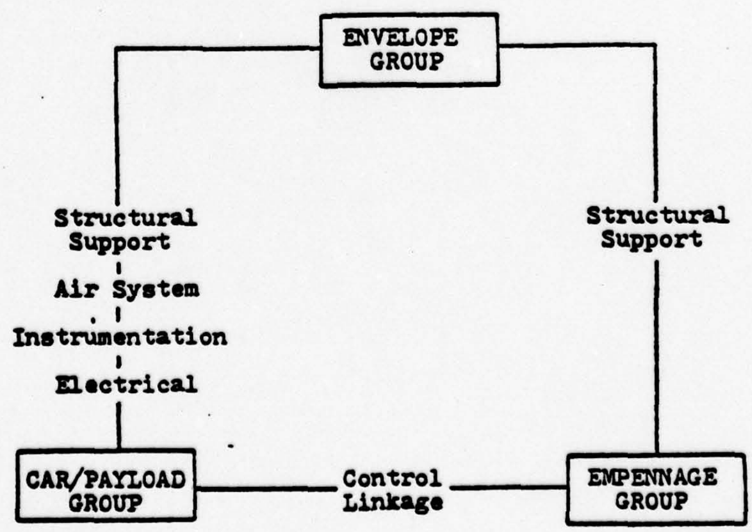

Fig. 11. Interfacing Requirements of Major Vehicle Groups

by previous designs. Therefore, separation of the empennage group into a module does not appear to be a problem. Figure 12 shows areas of reinforcement of the envelope required for multi-configuration capability. Therefore, it is proposed that the test vehicle be constructed in this manner to provide for reconfiguration of the tail to the three configurations previously shown in Figure 9. The inverted Y configuration would be limited to having the two lower control surfaces located at angles of 45 degrees below the horizontal. Guying is provided by suspension cables as shown in Figure 13 for the inverted Y, and Figures 14 and 15 for the cruciform and X tails, respectively.

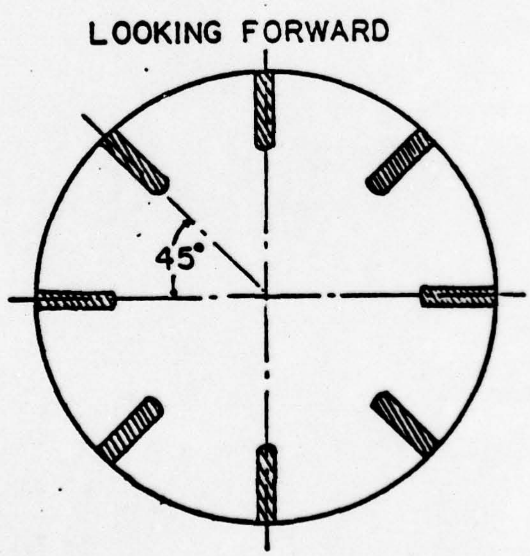

Fig. 12. Envelope Reinforcement for Multi-Configuration Empennage

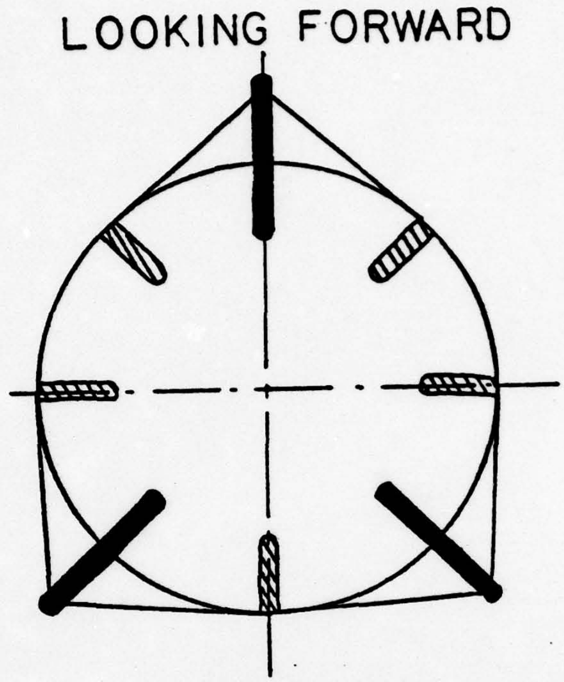

Fig. 13. Inverted Y Empennage Mounting

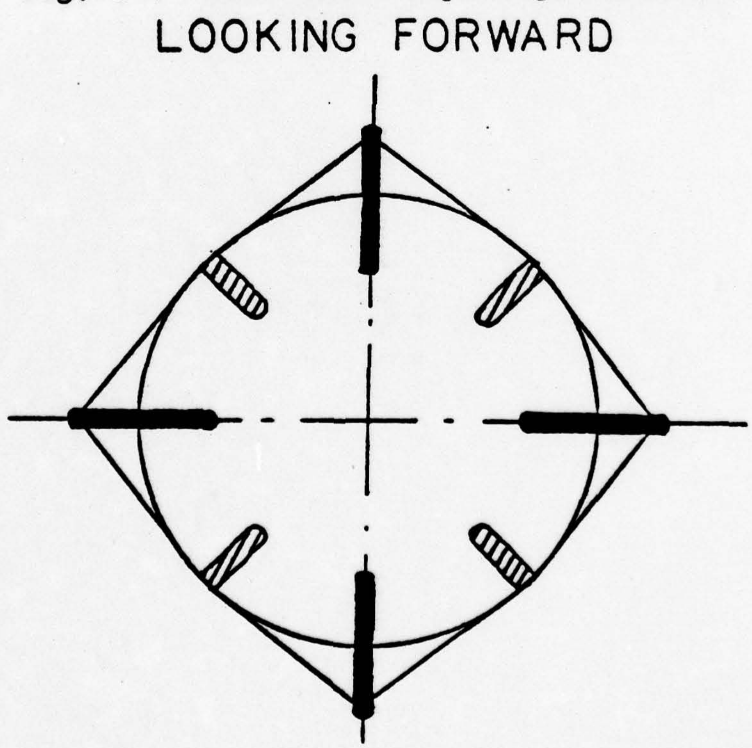

Fig. 14. Cruciform Empennage Mounting

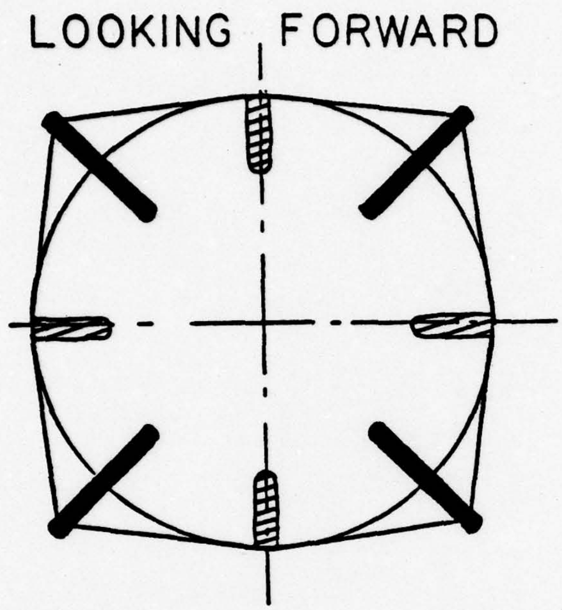

Fig. 15. X-Tail Empennage Mounting

Load carrying ability of the reinforced envelope must be examined in detail during the design phase. However, it is felt that this presents no major design problem.

Due to the available configurations of the tail, the control system would have to be modified for each configuration. The system providing for the least complexity is the cruciform configuration. This configuration functions like the tail control surfaces of a conventional aircraft, with rudder and elevator. However, for the other configurations mixers must be provided. These modifications would take place in the car/payload group. A simpler approach is discussed later.

D. ENVELOPE MODULE

As can be seen in Figure 11, the most complex interface is between the car/payload and envelope groups. Electrical and instrumentation interface can be accomplished by use of common connectors. However, the air system and support present other problems.

It is therefore proposed that an interface component be introduced to provide the isolation necessary to create the car/payload and envelope modules. This module interfacing component (MIC) would provide connections for the instrumentation and electrical requirements and contain the air system with one common connection for the car/payload. This component would be an integral part of the envelope with suspension cables from the envelope connected to the MIC permanently with tensioning adjustment capabilities provided in the MIC. The load from the car/payload would be transferred to the envelope through a mechanical connection to the MIC. External suspension, required for shear loads, would be provided between the envelope and the MIC. This would allow various configurations of the car/payload to be mounted on the envelope. Candidate car/payload configurations for the test vehicle would be of a generally conventional approach and an HLA approach as will be discussed.

A discussion of the construction of the envelope module is now possible. The envelope would be conventionally shaped as previously discussed. The use of modern, light-

weight fabrics would be examined for use in the originally delivered vehicle. A two-ply coated polyester fabric is proposed. The use of two-ply construction rather than single-ply as used on the AD-500 is proposed for reasons of reliability required by the vehicle. Since the vehicle is not proposed as an operational, mission oriented vehicle, weight savings must be secondary to availability. However, follow-up envelope modules with various materials and construction techniques could also be tested.

Envelope sizing would be accomplished as discussed in Appendix A. This is not considered important to the conceptual design and would be determined by test requirements.

The internal suspension system would be of conventional design. The use of modern materials should be investigated for possible use. Two catenary curtains would be used versus the four-curtain system used on larger vehicles.

The external support for the empennage module has been previously discussed and is not repeated here.

A two-Ballonet system, one forward and one aft, is proposed. The air system would be contained within the MIC connected on either end with the air lines to the Ballonets.

The valving system could either be located on the envelope or within the MIC. Although existing valve designs could be used, it is felt that a re-evaluation of valve design and construction is considered appropriate due to the advent of new materials and design techniques. Since the valves determine climb performance and rate of

descent, allowance for the evaluation of airship performance utilizing valves of various designs should be provided. This could be done by use of a standardized mounting "ring" on the envelope, or by replacement of the valve system within the MIC providing ease of replacement.

An area of great concern is the nose cone and mooring system. It was seen from the ground mishap of the AD-500 that utilization of modern techniques and materials has little advantage if failure occurs due to design or fabrication errors. Composite materials do offer considerable weight advantages; however, it must be kept in mind that the properties of these materials differ from those of conventional materials, and that a replacement part must be designed to take loads in a different manner. Therefore, any structure used for the nose cone constructed from such materials must undergo loading tests under all conceivable operating conditions. Oscillatory and vibration response must be examined as well as structural failure due to delamination. It is also possible that sensing elements, such as optical fibers, can be integrated into the material during fabrication to monitor fatigue in the structure. Fabrication must take place under controlled conditions for layered materials to prevent separation due to improper curing.

The mooring system can be of conventional design on the original vehicle. However, the dynamics of the vehicle while moored should be examined to determine if modifications to the mooring system are necessary. Therefore, the mooring

system should be capable of replacement as discussed for the valves. One of the areas of primary interests in the test phase would be the dynamic interactions of the mast and the vehicle during gust conditions. A possible adaptive mooring system may be possible to dampen oscillations and interactions which may occur.

The MIC is the major focus of the modular design approach. This component would allow removal of the car/payload module from the envelope module without full or partial deflation of the envelope. The netting procedure also used in the car removal for previous airships would also not be necessary. Another advantage is in the reduction of overall height allowed by the removal of the car/payload further enhanced by empennage module removal.

Some of the systems contained within the MIC would be:

- Air system and ducting to forward and aft Ballonets
- Air system control linkages
- Instrumentation and electrical connections
- Tensioning control adjustment
- Inspection domes and access ports
- Blower for air system
- Envelope rip cord control

Other components such as control linkages to the empennage module could also be contained in the MIC.

Figure 16 shows an example approach of the MIC design. The figure shown contains only the major air system

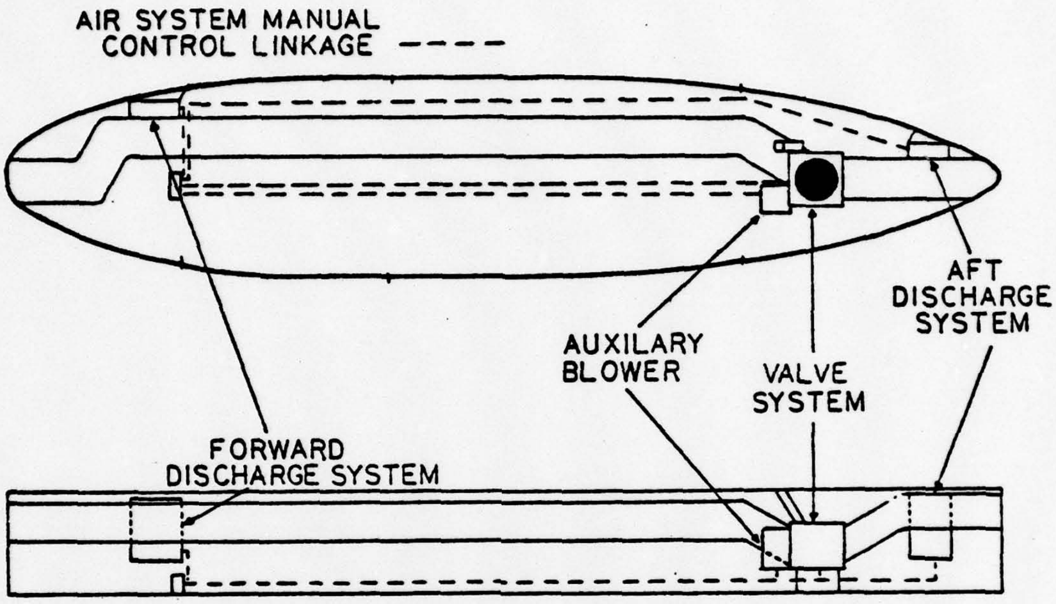

Fig. 16. Approach to Module Interfacing Component

components required, however, and the other systems could be located as desired within design constraints. The air system manual controls would be located at the bottom of the MIC and would mate with an opening in the overhead of the flight deck section of the car/payload module allowing easy access by the pilot. The air input from the car/payload module would be through the large, circular opening on the valve system. It is also possible to mount airstream intake scoops on the MIC itself, thereby eliminating the need for this interface connection. However, whenever air is to be supplied from the car/payload module, the design of the module must allow for correct mating with the valve system.

The design of the suspension cable and mechanical connections would be made after a detailed analysis of the vehicle loads is completed. This would also be accomplished for the tensioning adjustment system.

The envelope module could be stored and shipped in a package utilizing the MIC for the supporting base structure. A generalization of this is shown in Figure 17.

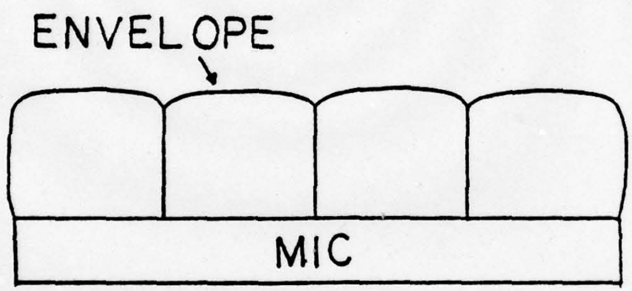

Fig. 17. Envelope Module Storage/Shipping Configuration

E. CAR/PAYLOAD MODULE

The car/payload module would be replaceable and could be mission oriented. However, it is proposed that three modules be originally supplied with the test vehicle.

Figure 18 shows the conventional module to be used for data collection. This module contains the following sections: flight deck, data analysis, payload, and engineering. Except for the data analysis section, these were previously discussed. The data analysis section could also be considered a mission oriented area since it would perform the

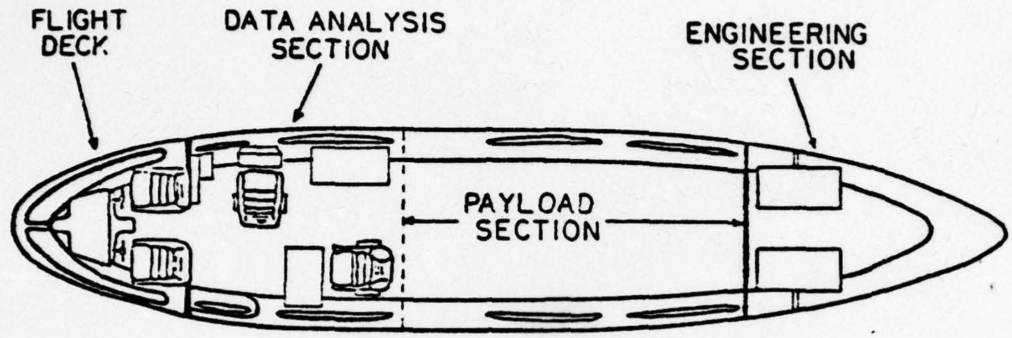

Fig. 18. Conventional Car/Payload Module

collection and analysis of data during test and research flights.

The propulsion proposed is by use of diesel driven, tiltable, ducted fans. Due to a growing interest in lightweight diesel development for light aircraft use as discussed by Ref. 25, it may be necessary for future replacement of engines to provide testing and evaluation for LTA use. Therefore, provisions should be made for this possibility.

It should be noted that ample payload space is still available in the conventional module. This could be used for purposes that are necessary for the tests and evaluations. The following presents an example of such a use. The conventional module would not necessarily be required to carry a large amount of fuel, normally two to four hours, since its primary purpose would be that of data collection. However, if endurance, range or habitability of the vehicle is

to be examined, then the payload section can be configured for crew quarters and/or increased fuel load.

The second car/payload module configuration would be constructed for the evaluation of HLA flight. An example of such a vehicle without empennage module is shown in Figure 19, with the corresponding car/payload module shown in Figure 20. It should be pointed out that these are concepts and that detailed design would determine the final configurations. Reinforcement modifications to the module could possibly be necessary for support of slung loads.

The third car/payload module would basically be an empty shell to be configured as desired during the tests and evaluation of the vehicle.

It should be pointed out at this point that further modularization could be accomplished by creating a payload section module such as the passenger/cargo module of Ref. 1. However, this should be left to the program office for the determination of the specific approach.

Many of the tests would involve hoisting and launching operations, such as boat launch, cargo/crew hoisting, surface-to-air refueling, and towing. Therefore, it may be necessary to modify the third module to provide for bottom access and reinforcement for wench mounting. Once again, this should be determined by the specific requirements.

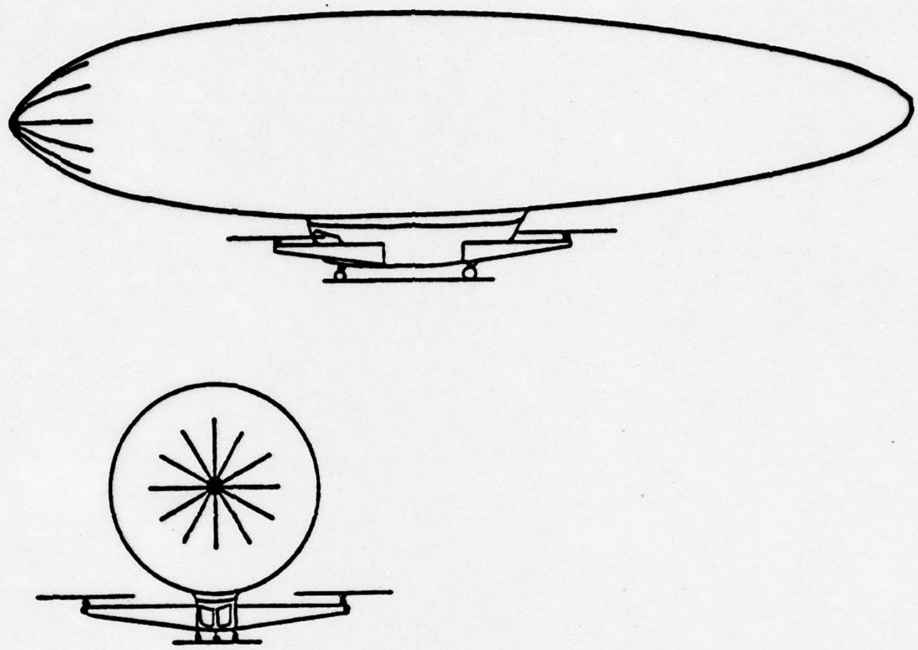

Fig. 19. Test Vehicle in HLA Configuration

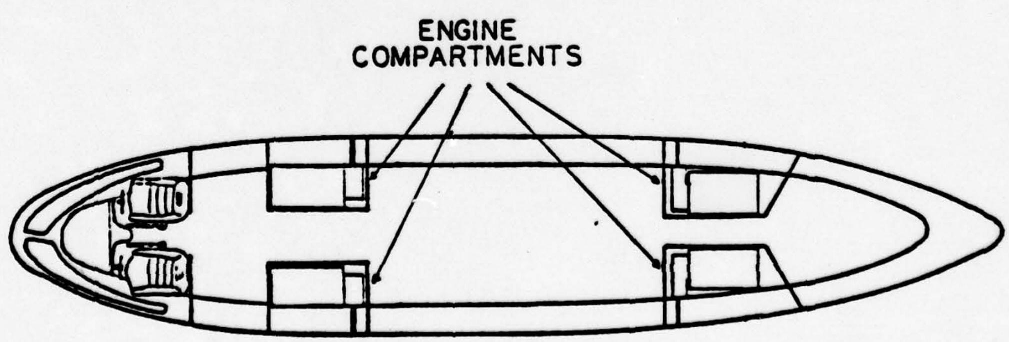

Fig. 20. HLA Car/Payload Module

F. OTHER CONSIDERATIONS

As was previously mentioned, the modification of empennage configuration would require a modification in control systems. A conventional cable control system could be installed, with the capability of performing the three control system approaches. There would be common elements within the systems; however, substantial weight penalties could be presented. Therefore, the use of fly-by-wire techniques would appear to be the most desirable. Not only could the "black box" approach be used in changing control systems, but control laws could be modified by software manipulation in digital systems. This would provide additional test and evaluation capabilities for flight dynamics and stability studies. Interface between car/payload and empennage modules could be of conventional fly-by-wire techniques or the use of redundant optical fibers. A comparison of optical fiber and conventional coaxial methods is shown in Table I from Ref. 26. If the optical fiber approach is used, these could be made a part of the envelope module connecting on one end to the empennage module and on the other through the MIC to the car/payload module. The use of the fly-by-wire approach appears quite attractive; however, cost and mechanical backup capabilities must be taken into consideration.

Special support equipment for removal of the car/payload module and handling of the envelope module would

ATTRIBUTES	OPTICAL	COAXIAL
Size	0.18 inch dia.	0.48 inch dia. for low loss cable
Electromagnetic Interference	Totally free and no grounding or ground loop problems	Satisfactory with heavy shielding
Practical Data Rate Capability MEGBITS/SEC	Light emitting diodes 10 MEGABIT/SEC 1974 50 MEGABIT/SEC 1975 300 MEGABIT/SEC 1980	200 MBITS/SEC
Interconnect	3 db Loss but improving	Low loss
Cost	Eventually, Lowest	--------
Redundancy	400 Fibre/Bundle	Single Center Conductor
Power Consumption	1 Watt	2 Watts
Weight	12 lbs for a 30 ft bundle	80 lbs for a 30 ft bundle
Fail Safety	Inherent short circuit protection	Will cause failures in other systems

Table I

Comparison of Optical Fiber and Coaxial Connector Cables [Ref. 26]

be required. However, the advantages gained by the modular approach for the test vehicle would outweigh the cost of such equipment.

Three pieces of equipment would be required: expandable mast, car/payload support equipment, and envelope handling equipment. The expandable mast would be necessary so that the nose of the airship could be lowered after removal of the car/payload. This presents no major problems with current design practices.

An approach to the car/payload and envelope handling equipment is shown in Figure 21. In this figure, (A) indicates the car/payload support portion of the equipment which functions as a cradle for the car/payload module. Prior to removal of the car/payload, the MIC of the envelope is secured to the envelope handling equipment, indicated by (B) in the figure. The car/payload is then removed and the support equipment pulled away from the envelope handling equipment. It is obvious that the envelope handling equipment must be weighted to the value of the car to maintain the vehicle in ground contact. Therefore, heavy materials and/or ballast are used.

The approach shown is conceptual and design analysis is necessary for the final equipment.

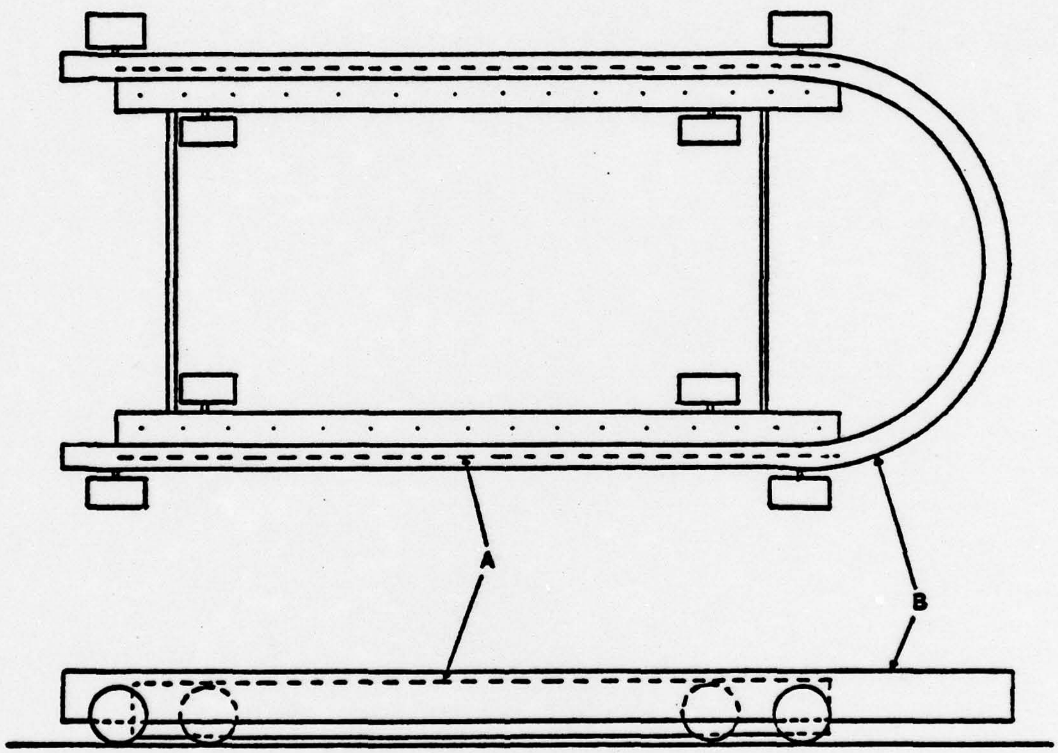

Fig. 21. Car/Payload and Envelope Module
Handling Equipment

IV. TEST PROGRAM

A. GENERAL

A general approach to the test program is now presented. This program would be broken into phases as shown in Figure 22. It can be seen from the figure that the program is cyclic in nature to allow for vehicle modification and reconfiguration. The use of more than one car/payload module would minimize down time since modifications could be made to one module while the other module on the vehicle is performing the other phases of the test program.

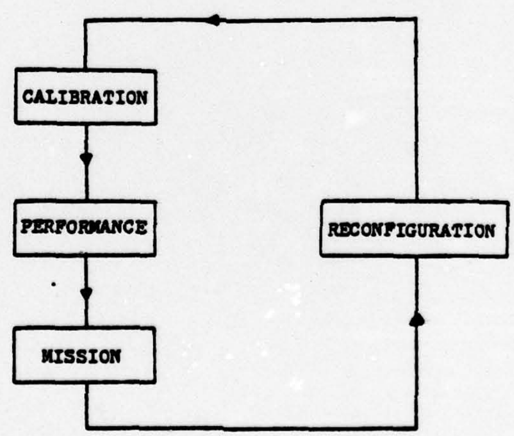

Fig. 22. Test Program Approach

B. CALIBRATION PHASE

Once the vehicle is prepared for flight, the calibration phase of the program would begin. Examples of tasks to be conducted during this phase are:

- Calibrate flight instruments (such as airspeed system).
- Calibrate data instrumentation sensors.
- Perform envelope measurements to determine possible deformations.
- Perform necessary maintenance and checkout of vehicle support equipment to ready vehicle for flight.
- Perform tests to ensure safety of flight.

This is a preparatory phase of the program to provide baseline data for the following phases and would be accomplished after any reconfiguration of the test vehicle.

C. PERFORMANCE/MISSION PHASE

The performance phase of the program would consist of the evaluation of the flying qualities of the vehicle as well as its performance characteristics. In addition, the dynamic and static stability of the vehicle would be examined. Some of the possible areas of investigation are given in Table II.

Procedures for conducting such tests can be found in Refs. 27 and 28 and other such flight test manuals. Tests primarily designed for airships, such as deceleration tests for determination of drag, are discussed in Refs. 29 and 30.

Propulsion Efficiency

Cruise Performance
- Drag
- Thrust
- Dynamic and Static Lift

Climb Performance
- Excess Power Available
- Maximum Rate of Climb
- Maximum Rate of Descent

Takeoff/Landing Performance
- Wind Limitations
- Engine Out Performance

Turning Performance
- Forces in Turn
- Minimum Turning Radius
- Limitations

Hover Performance
- Wind Limitations
- Lift in Hover

Ground Handling Performance

Towing Performance
- Capacity
- Hardpoints/Loads
- Maneuverability

Longitudinal Static Stability
- Pitching Moment
- Control Efficiency
- Stick-Fixed and Stick-Free Stability
- Speed Stability
- Flight Path Stability

Longitudinal Maneuvering Stability
- Stick-Fixed Maneuver Stability
- Stick-Free Maneuver Point

Lateral Static Stability

Directional Static Stability

Directional Control
- Asymmetric Power
- Crosswind Performance

Dynamic Stability
- Longitudinal Dynamic Stability
- Lateral-Directional Dynamic Stability

Handling Qualities
- Pilot/Crew Workload
- Control Power

Maintenance and Support Performance

Table II

Areas of Investigation for Performance Phase Tests

The mission phase of the program would be determined by user inputs. This would range from the comparatively simple evaluation of the vehicle as a platform for sensors to the more complex testing of boat launching and retrieval. Specific examples of these tests are not given here but would be developed based on the integration of user inputs.

It should be pointed out, however, that there would exist capabilities of performing many mission and performance tests simultaneously. Although this would reduce testing time, it may not be advantageous to the program. It is felt that by separating the tests, baseline data would be established during the performance phase, and these data would not be contaminated by mission oriented evaluation procedures. It must be remembered that the proposed vehicle is a test vehicle, not an operational vehicle from which test data is to be gathered [Ref. 18].

D. RECONFIGURATION PHASE

The reconfiguration phase would be devoted to the reconfiguration of the vehicle for the next test series. Modifications can be made during this phase as dictated by the analysis of previous performance tests.

It is to be emphasized that the use of multiple car/payload modules would reduce the time required for this phase. In addition to this, the use of multiple envelope module configurations would allow simultaneous work to be carried out in the various phases, thus providing a cost optimization.

E. DATA REQUIREMENTS

The data gathered from the vehicle can be categorized into groups as shown in Figure 23. Examples of the types of data collected is also shown. Computations utilizing this data would be made to output the desired results for analysis.

Tests for determining the effects of envelope-rotor interference in the HLA configuration and other concepts only model-tested to date would be accomplished as well as examination of control laws to be utilized in future vehicles.

AEROSTATIC

Air System (Flow)
Ballonet Pressures
Gas Pressure
Gas Temperature
Ballonet Air Temperature
Center of Buoyancy
Heaviness (Weight)
Static Trim

STRUCTURAL

Rudder and Fin Loads
Envelope Loads
Catenary/Suspension Loads
Landing Gear Loads
Mooring Loads
Car/Payload Loads
Vibrations
Center of Gravity

FLIGHT DYNAMICS

Aerodynamics
Skin Pressures
Roll/Roll Rate
Pitch/Pitch Rate
Yaw/Yaw Rate
Air Flow (Tuffs)
Center of Pressure
Angle of Attack
Stick Control Forces
Stick Displacements
Control Surface Displacements
Moments

ENGINEERING

Engine MAP
Engine Temperature
Engine RPM
Throttle
Torquemeter
Blower Speed
Electrical Status
Avionics Status
Transmission Data
Fuel Flow

ENVIRONMENTAL

Outside Air Temperature
Humidity
Barometric Pressure

EMERGENCY

Fire Detection

ECONOMIC

MISSION

Fig. 23. Test Data Organization

V. INSTRUMENTATION

The vehicle proposed is intended primarily for test and evaluation purposes. Therefore, the use of modern, high-technology sensors and instrumentation would be essential to a productive effort. Modern aircraft flight testing on vehicles such as the F-14, F-15, F-16 and F-18 has served to advance the state-of-the-art in flight test instrumentation. This, coupled with the advancements in the field of microprocessor technology, has made the possibilities seemingly limitless for onboard data collection and analysis, including real-time analysis.

The extensive use of strain measurement gages on the envelope and structural surfaces is envisioned. Sensors for measurement of air flow rates would be used throughout the air system, as well as sensors for determining the motion and motion rates. All of these, along with pressure and temperature sensors, would be integrated into a data collection system designed around the use of modern microprocessors. The use of such a large amount of sensors would possibly necessitate the use of memory mapping versus conventional input/output data bus operation of the computer system. Such an approach is discussed in Ref. 31.

The data collection system would not only be capable of performing its primary role but could also supply vehicle state information. This information could be given in the

form of a display of the vehicle indicating actual shape and critical loads and pressures as well as engineering and other operator selected information.

Modern avionics systems also benefit from recent developments. As was previously discussed, the use of fly-by-wire techniques would not only allow for weight reduction, but also flexibility and higher reliability. This can be applied throughout the avionics systems, and especially the air data computer. Recent developments in air data sensors is discussed in Ref. 32. Although many of these concepts can be applied to an LTA vehicle, the area of helicopter and vertical/short takeoff and landing (V/STOL) sensors should be examined closely. A characteristic shared by these and LTA vehicles is that of omnidirectional, low-speed flight. The design and location of a pitot-static pressure probe for such a system is unique to these vehicles. That is further complicated in the LTA vehicle by the existence of large boundary layers. Therefore, the selection and location of this sensor requires study and evaluation during the calibration phase of the test program.

Examples of operational instrumentation for earlier airships is given in Table III. This is shown to furnish an idea of what instrumentation would be necessary for airship operation.

Although this discussion on the vehicle's instrumentation is brief, a large percentage of the program workload would be involved in design of this system from the user and technology inputs to the program.

Airspeed Indicator

Superheat Meter

Air Temperature Indicator

Air Scoop Position Indicator

Elevator Position Indicator

Radio Altimeter Indicator

Sensitive Altimeter Indicator

Rate-of-Climb Indicator

Inclinometer

Gyrosin Compass Indicator

Radio Compass Indicator

Rudder Position Indicator

Standby Compass

Engine Instruments

- Dual Tachometer and Synchroscope
- Dual Manifold Pressure Indicator
- Cylinder Head Temperature Indicator
- Dual Thermometer Indicator
- Engine Gage Units
  - Fuel and Oil Pressure and Oil Temperature
- Oil Quantity Gage
- Carburator Air Temperature Indicator

Miscellaneous

- Clock
- Liquid Manometer
- Mechanical Manometer
- Ammeter
- Voltmeters
- Free Air Temperature Indicator
- Fuel Quantity Gages
- Auxilary Power Plant Oil Temperature Gage

Table III

Operational Instrumentation Requirements of Early Airships

VI. CONCLUSIONS

This work presents a concept for use in the development of LTA technology. It is felt that such an approach is necessary if any advancement is to be made in this long-neglected vehicle.

Further research is indicated in the area of a fly-by-wire control system for such a vehicle, vehicle instrumentation, and vehicle detailed design. Although the control system can be examined prior to the initiation of the program management, many other questions require the inputs of the organizations discussed.

Modern airships do not strain the available technology. This has been proven by the recent AD-500. However, until such time as a test vehicle is constructed and flown utilizing these modern techniques, the concept of LTA for modern uses will continue to be one of feasibility studies and quite advanced designs. There has probably existed no other concept that has been studied to the extent of the airship. However, these vehicles have not yet been put to their potentially productive tasks.

APPENDIX A

VEHICLE SIZING COMPARISONS

As pointed out by Burgess in Ref. 32, two important coefficients are required in determining the dimensions of an airship and its volume. The first of these is the fineness ratio. This is defined as the overall length of the vehicle divided by its maximum diameter and is given by:

$$F = \frac{L}{D} \qquad (4)$$

where: F = fineness ratio

L = vehicle overall length

D = vehicle maximum diameter

This coefficient is also known as the slenderness or elongation ratio.

The second coefficient of interest is known as the cylindric coefficient (C_v). This is defined as the actual volume of the vehicle divided by the volume of a cylinder with the same length and maximum cross-section as the vehicle. Therefore, as the cylindric coefficient approaches unity, the shape of the vehicle approaches that of a cylinder.

It is obvious that the shape of the vehicle will affect its drag. A fineness ratio of from 4.5 to 5.0 and a cylindric coefficient of 0.60 to 0.65 were given by Burgess to appear to present the least aerodynamic drag.

The relationship between these coefficients and the vehicle's volume is given by:

$$V = \frac{C_v L D^2 \pi}{4} \tag{5}$$

or

$$V = \frac{C_v F D^3 \pi}{4} \tag{6}$$

where: V = Volume of vehicle

C_v = Cylindric coefficient

L = overall length of vehicle

D = maximum diameter of vehicle

F = fineness ratio

It was decided to examine past vehicles and their sizing utilizing these equations to determine proven coefficients for design.

The vehicles examined were Goodyear's U.S. Navy ZP2K [Ref. 34], ZP3K [Ref. 35], ZP2N [Ref. 36], ZPG-2 [Ref. 37], and the commercial America and Mayflower [Ref. 37]. In addition, the British AD-500 [Ref. 22] and West German WDL 1 [Ref. 38] were examined. The references indicate the sources of data used in the examination.

Table IV lists these vehicles as well as their dimensions, where available.

Vehicle	Length (feet)	Maximum Diameter (feet)	Volume ($feet^3$)	Average Tail Area ($feet^2$)	F	C_v	Calculated Tail Area ($feet^2$)
ZP2K	250.50	60.00	456,000	451.75	4.175	0.644	385.09
ZP3K	265.85	62.10	527,000	505.68	4.281	0.655	424.09
ZP2N	342.65	75.42	975,000	764.50	4.543	0.637	639.12
ZPG-2	339.00	75.00	1,011,000	764.50	4.520	0.675	654.76
AD-500	164.00	45.90	181,200	------	3.573	0.668	208.14
WDL 1	197.00	47.00	211,900	------	4.192	0.620	231.03
America	190.00	49.00	200,400	------	3.878	0.559	222.59
Mayflower	157.00	50.00	145,850	------	3.140	0.473	180.10

Table IV
Vehicle Dimensions and Comparisons

Using equation (4), the fineness ratio (f) was determined, and then by rearranging equation (6) to:

$$C_V = \frac{4V}{FD^3\pi} \qquad (7)$$

the cylindric coefficient was found. These results are also shown in Table IV. It can be seen that the cylindric coefficient ranged from 0.473 to 0.675, and the fineness ratio from 3.14 to 4.543.

Since the values of the cylindric coefficient ranged from approximately 0.55 to 0.70 for most vehicles, equation (7) was rearranged to:

$$D = \left[\frac{4V}{FC_v\pi}\right]^{1/3} \tag{8}$$

and diameters determined for various values of fineness ratio.

Once this was accomplished, the length was found by rearranging equation (4) to:

$$L = FD \tag{9}$$

This information was then plotted and is given as Figures 24, 25, 26 and 27. These are presented to allow preliminary sizing.

In addition to the above calculations, the average tail area was calculated from equation (3) and compared to the actual average tail areas. These actual average tail areas included the control surfaces and tabs. The results indicated a 16 to 19 percent increase in the actual size of the tail surfaces compared to that given by equation (3). Therefore, this should be considered in tail surface sizing. A plot of tail surface average area was given previously as Figure 10. This did not take into account the discrepancy between the theoretical and empirical data.

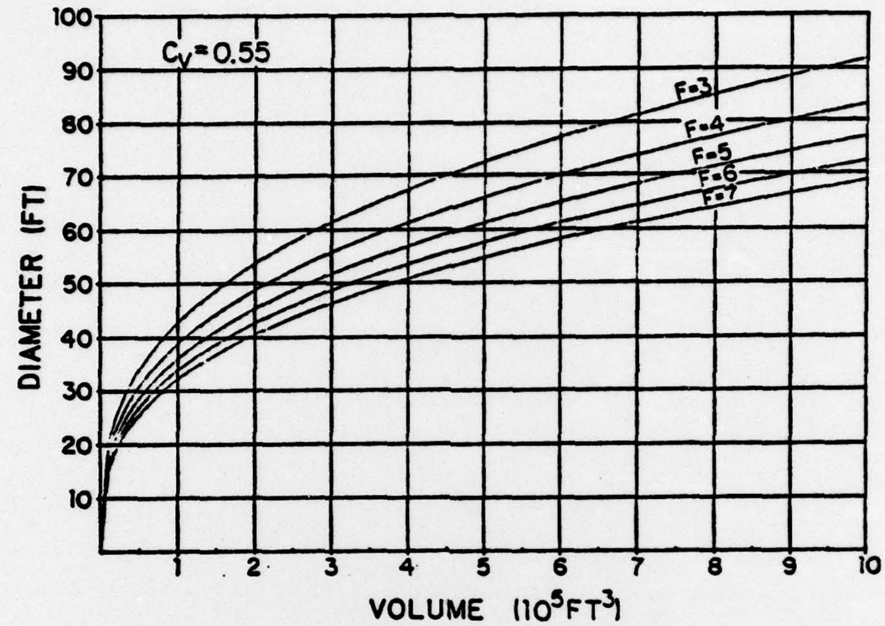

Fig. 24a. Vehicle Diameter vs. Volume - C_V = 0.55

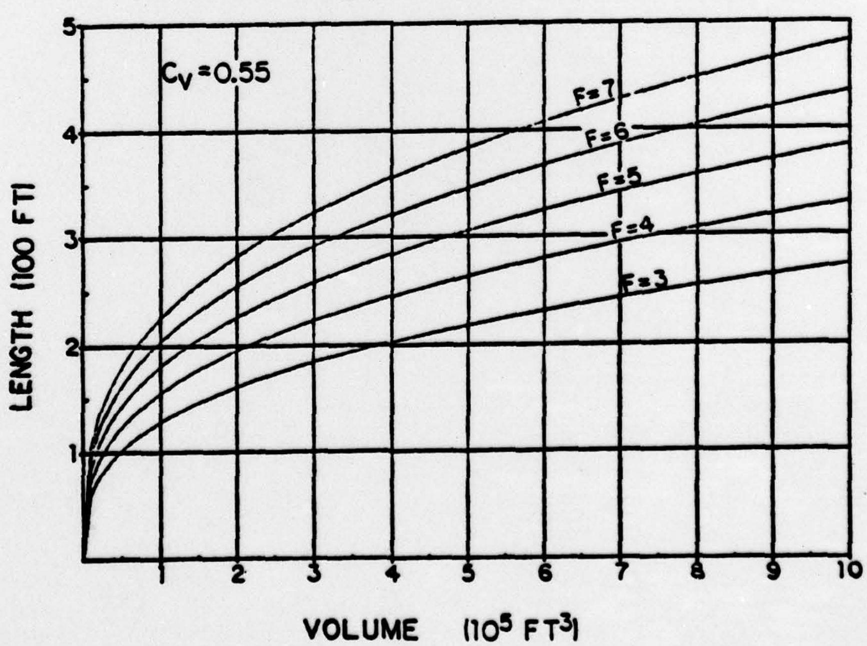

Fig. 24b. Vehicle Length vs. Volume - C_V = 0.55

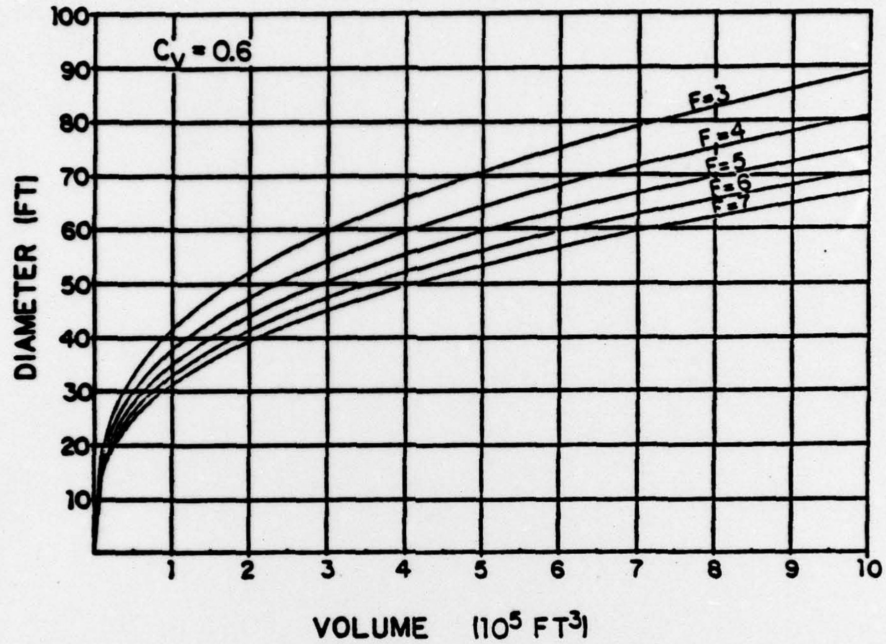

Fig. 25a. Vehicle Diameter vs. Volume - $C_v = 0.6$

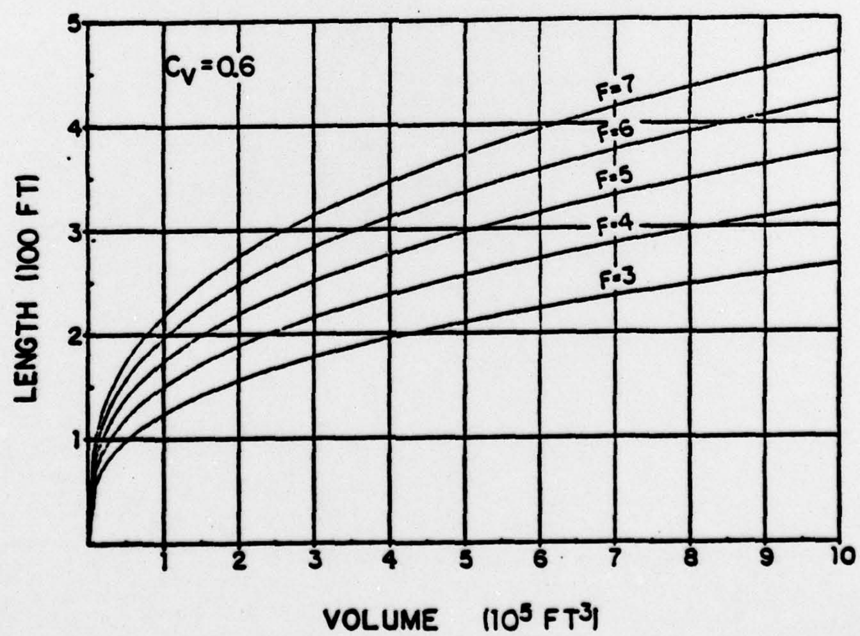

Fig. 25b. Vehicle Length vs. Volume - $C_v = 0.6$

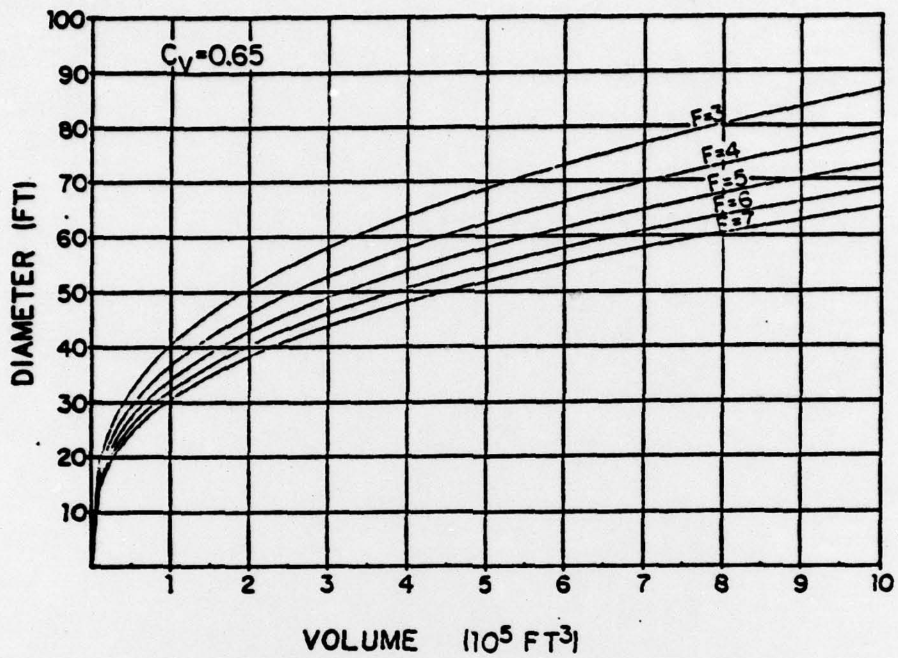

Fig. 26a. Vehicle Diameter vs. Volume - C_v = 0.65

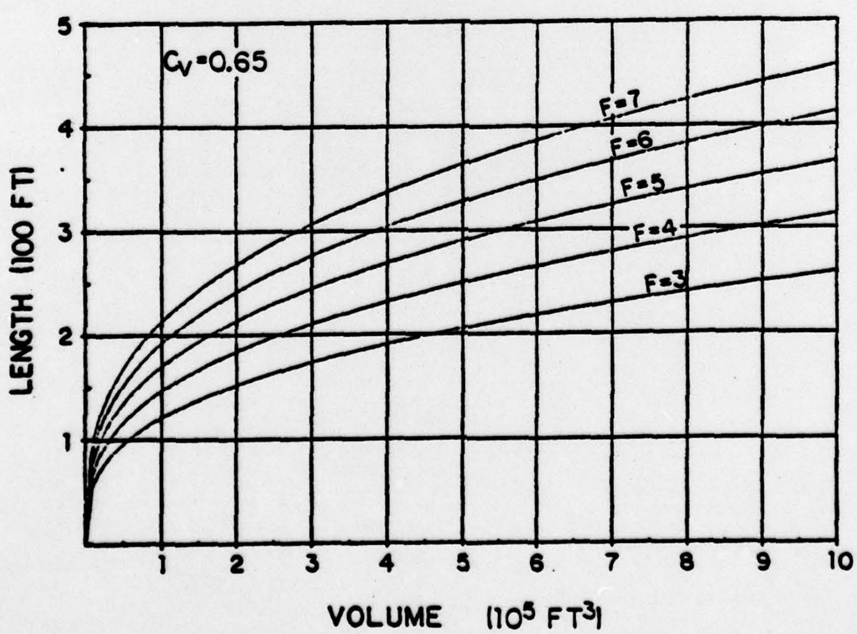

Fig. 26b. Vehicle Length vs. Volume - C_v = 0.65

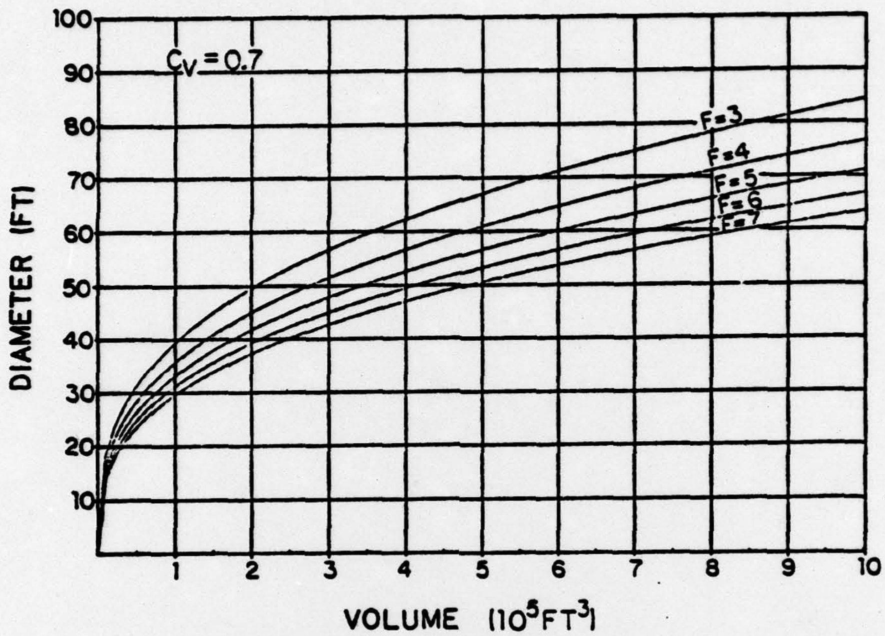

Fig. 27a. Vehicle Diameter vs. Volume - C_v = 0.7

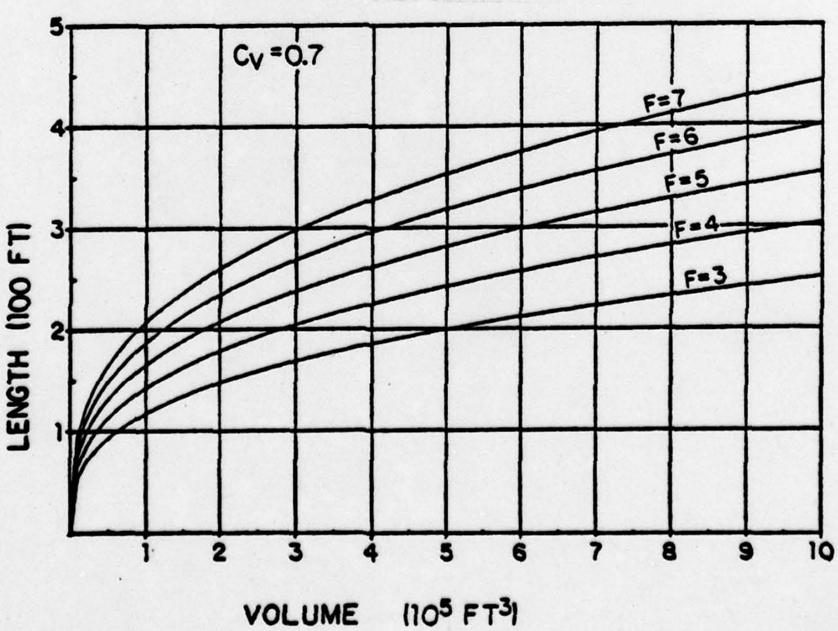

Fig. 27b. Vehicle Length vs. Volume - C_v = 0.7

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